Long-term changes in aquatic vegetation associated with structural modification and altered hydrology in a subtropical east Australian estuary

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ABSTRACT

A *Zostera capricorni* community is formally recorded for the first time in Currumbin Creek on the subtropical east Australian coast. The seagrass community extends approx. 2 km along both sides of the creek just below low tide mark, growing either in patches of variable size or more commonly as broad bands up to 5 m in breadth. The community consists of dense subtidal *Zostera capricorni* plants growing with subtidal *Halophila ovalis*. Leaves of *Zostera capricorni* were typically up to 70 cm long, considerably longer than previously reported for the large growth form of the species. Biological surveys undertaken over the last two decades had reported seagrasses as absent from Currumbin Creek. However, a forgotten consultancy report documented the loss of a small *Zostera capricorni* community in the creek following large-scale dredging of the internal delta in 1974. It is unlikely that seagrasses would have recolonised Currumbin Creek until after the cessation of sand dredging in 1992. Recent extension of the seagrass community much further upstream than previously reported is consistent with the change to marine conditions following training wall construction in 1973 which maintains the creek mouth permanently open to the sea. Previously, lower Currumbin Creek had oscillated between a prolonged freshwater phase when accumulated sand isolated the creek from the sea and a shorter marine phase that followed episodic high runoff events when the flooded creek cut a new entrance to the sea. Lessening of the freshwater influence has produced environmental conditions more conducive to seagrass growth and has also led to the replacement of freshwater riparian vegetation with mangroves. Seagrasses are a valuable resource in coastal marine ecosystems and it is essential to develop management strategies to ensure the survival of the Currumbin Creek seagrass community. ❑ *Zostera capricorni, Halophila ovalis, expanding seagrass community, habitat modification, sand dredging, Currumbin Creek, Australia.*

Negative impacts of increasing population and coastal development on the biota and ecosystem integrity of coastal southern Queensland have long been recognised (Coaldrake 1961; Saenger & McIvor 1975; Thompson 1975; Co-Ordinator-General 1975; Hyland & Butler 1988; Hyland *et al.* 1989). The 200 km stretch of coastline from Noosa (26°23′S, 153°06′E) to Coolangatta (28°10′S, 153°33′E) on the Queensland/New South Wales border, known as the 'Sunshine Coast' to the north and the 'Gold Coast' to the south of Brisbane (27°28′S, 153°01′E),

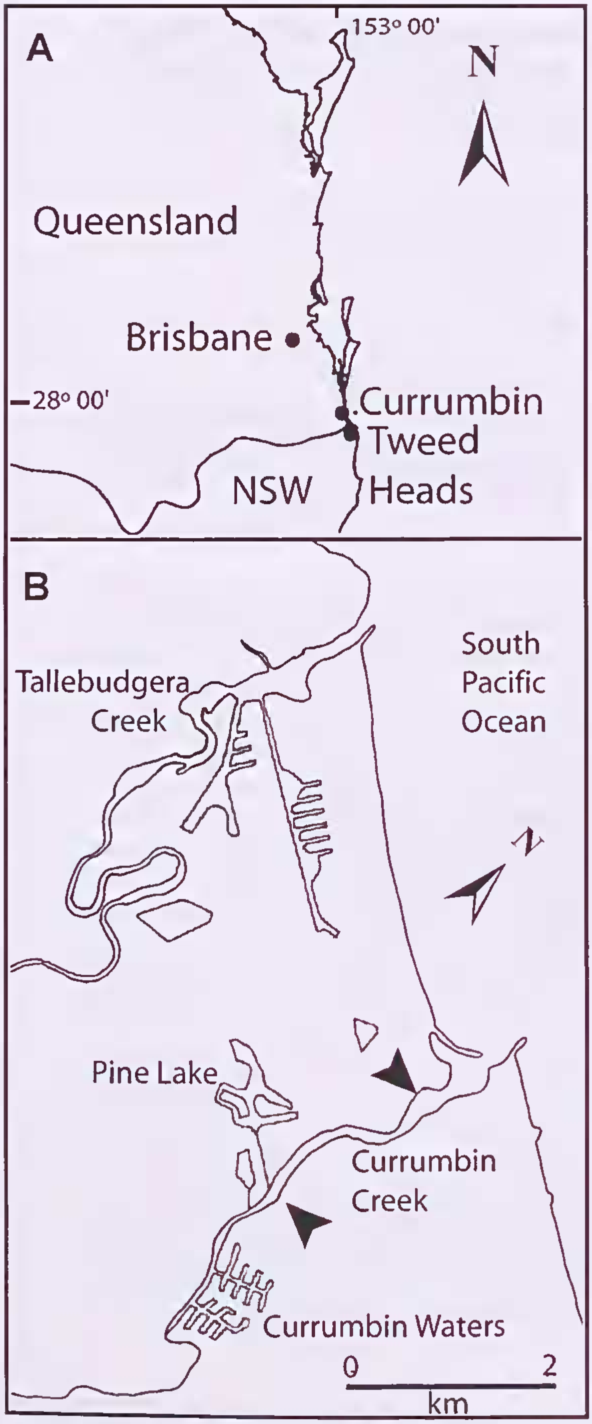

FIG. 1. Maps of Currumbin Creek, SE Queensland, Australia. A, location in relation to Brisbane and the Gold Coast. B, showing the extent of the *Zostera* community marked by arrowheads; the downstream limit is close to the creek mouth and the upstream limit is near the outlet to Pine Lake.

has been popular as a recreational destination since the 1950s and as a residential area for the last 3 decades. This coastal development has resulted in the large scale loss of the terrestrial heath ecosystem (the wallum), the draining of wetlands and the modification of estuaries. By 1975, residential canal developments had been constructed on 8 of the 14 major estuaries within 130 km of Brisbane resulting in the loss of large areas of saltmarsh and mangroves (Saenger & McIvor 1975). Currently, an urban strip extends along the southern Queensland coast from Noosa to Coolangatta.

With the exception of Moreton Bay, little is known of the aquatic biota of southern Queensland estuaries. There have been no systematic biotic surveys which have monitored the estuarine species of the region. Compared to many other regions of the world, the few biological surveys of southeast Queensland estuaries are relatively recent, first undertaken by conservationists from the Queensland Littoral Society (Lewis & Ellway 1971; Ellway & Hegerl 1972; Hegerl & Timmins 1973; Shine *et al.* 1973) in order to document a biota threatened by habitat destruction from real estate and other developments. Other data on estuarine organisms in the Gold Coast region exists in reports by consultancy companies (Consultancy Study Group 1974; Saenger & McIvor 1975; Hollingsworth 1975; WBM Oceanics 2000) and Queensland Government departments, the latter including the Coastal Management Investigation for southern Queensland (Co-Ordinator-General's Department 1975) and surveys of mangrove (Hyland & Butler 1988) and seagrass communities (Hyland *et al.* 1989). However, retrieving data from consultancy and government reports is often difficult, as these reports are held by few libraries, are not indexed in scientific databases and are often forgotten with the passage of time. Major gaps in our knowledge base of species inhabiting southern Queensland estuaries still exist and the new data generated from current studies need to be stored in the widely accessible scientific literature.

Seven species of seagrasses are recorded for southern Queensland (Young & Kirkman 1975; Poiner 1984; Hyland *et al.* 1989) and an eighth species is newly recorded in this volume (Phillips *et al.* 2008). *Zostera capricorni* Aschers. is widely distributed in sheltered bays, coastal lagoons and estuaries along the east Australian coast, growing intertidally and/or subtidally, often in a monospecific community or with *Halophila ovalis* (R.Br.) Hook f. In Moreton Bay, *Halophila spinulosa* (R.Br.) Aschers. and *Halophila decipiens* Ostenf. are usually subtidal species and *Halodule uninervis* (Forsk.) Aschers. frequently grows on sandy substrata. *Cymodocea serrulata* (R.Br.) Aschers. and *Syringodium isoetifolium* Aschers. are largely confined to the eastern oceanic influenced waters of Moreton Bay (Young & Kirkman 1975; Poiner 1984).

Previous surveys had reported Currumbin Creek on the subtropical east Australian coast (Fig. 1) to be devoid of seagrasses (Hyland *et al.* 1989; WBM Oceanics 2000). This paper reports the discovery of an extensive, dense, subtidal *Zostera capricorni* meadow in lower Currumbin Creek during a biotic survey undertaken in 2003 by GHD Pty. Ltd. for the Gold Coast City Council. The Currumbin Creek *Zostera* community comprises plants with considerably longer leaves (to 70 cm long) than the large growth form of the species reported from nearby Moreton Bay. A consultancy report has been located documenting the presence of a small seagrass community near the mouth of Currumbin Creek in 1974. The factors which presumably have facilitated the recent recolonisation and expansion of the current Currumbin Creek seagrass community are discussed.

METHODS

STUDY AREA

Currumbin Creek drains a narrow steep sided valley and flows into the South Pacific Ocean. Rainfall is highly seasonal and freshwater runoff from the Creek is markedly variable both seasonally and annually. The entrance of Currumbin Creek is kept permanently open to the sea and consequently lower Currumbin Creek functions as a tidal inlet (Consultancy Study Group 1974; D'Agata & McGrath 2002). The sandy substratum in the lower Currumbin Creek grades to mud approximately 2 km upstream from the entrance. The Pacific Highway bridges were constructed across Currumbin Creek in 1973/74 and two residential canal developments are located in the upper estuary.

PRESENCE AND EXTENT OF SEAGRASSES AND MANGROVES

Currumbin Creek estuary was surveyed by boat during a 0.11 m low tide on 11th October 2003. Seagrass distribution in the estuary was surveyed visually, recording distribution limits of the community. The extent, species composition and structure of the mangrove communities along the creek were also recorded.

Extensive searches of the scientific literature, consultancy and government reports, the Queensland Herbarium Database (HERBRECS), aerial photographs and historical photographic collections from libraries were undertaken in order to determine whether seagrasses grew in Currumbin Creek prior to or at any time since the commencement of large scale human development in the area in the 1950s. Presence and distribution patterns of mangrove communities fringing Currumbin Creek were also investigated as these communities are more frequently included in vegetation surveys, are easily visualised in historical and aerial photographs and are indicative of the brackish conditions suitable for seagrass growth.

RESULTS

Zostera capricorni grew in lower Currumbin estuary either as patches or as dense broad bands 1–5 m wide, parallel to the creek banks at depths of 0.5–1 m below low water level of the spring tides. No *Zostera capricorni* was found growing in the intertidal zone. The community extended from an upstream distribution limit at the outlet of Pine Lake on the northern creek bank, for approximately 2 km down both sides of the creek to just upstream of the Gold Coast Highway bridge (Fig. 1). The upper estuarine distribution limit of *Zostera capricorni* appeared to coincide with a change from sand/muddy sand to mud substrata, but this may be related more to turbidity as *Zostera capricorni* grows extensively on intertidal muddy substrata throughout Moreton Bay.

Leaves of *Zostera capricorni* grew to a maximum length of 70 cm, positioning the upper leaf blades in the well illuminated surface waters and permitting the extent of the *Zostera* community to be observed from above the water surface. The *Zostera* plants appeared healthy and actively growing with only small numbers

FIG. 2. **A**, Currumbin Creek, 1911, view looking upstream from Granny Birch's Island in the creek mouth (washed away by the 1931 floods), showing dense stands of *Melaleuca* along the creek banks and the lack of mangrove vegetation characteristic of tidal waters. (Image courtesy of the John Oxley Library). **B**, Currumbin Creek, 1904, view of the creek mouth looking north to Burleigh Headland, showing *Melaleuca* sp. growing on the northern creek bank on which mangroves now grow. (Image courtesy of the Gold Coast City Council Local Studies Library).

of algal epiphytes colonising the mature and senescing leaves. *Halophila ovalis* was observed to grow amongst *Z. capricorni* near the Pine Lake outlet as plants were inadvertently pulled free of the substratum when collecting specimens of *Zostera*. Destructive sampling would have been required to document the ecological distribution of the small *H. ovalis* plants growing in the turbid conditions in Currumbin Creek.

Avicennia marina (Forssk.) Vierh. (the grey or white mangrove) grew as broad continuous dense bands along both banks of Currumbin estuary to approximately 5 km upstream from the mouth. In the lower estuary, a few trees of *Rhizophora stylosa* Griff. (spotted or spotted-leaved red mangrove) grew on the seaward edge of the *Avicennia marina* community. Recruitment by many *Avicennia* seedlings was observed at several sites along the estuary.

There are no specimens of seagrass, collected *in situ* from Currumbin Creek, lodged in Queensland Herbarium (A. Bolin, Collections manager, HERBRECS database, Queensland Herbarium, pers. comm.). No published papers documenting the presence of seagrasses in Currumbin Creek were found from searching scientific databases, but the Libraries Australia catalogue listed consultancy reports recording seagrasses in Currumbin Creek in the early 1970s (Consultancy Study Group 1974; Hollingsworth 1975). In 1974, extensive beds of *Zostera capricorni* grew on protected sandbars on the northern bank inside the creek mouth, but this population was lost in 1975 following the destruction of the seagrass habitat from sand dredging.

Although not providing any information on the presence/absence of seagrass in the estuary, historical and aerial photographs of Currumbin Creek documented changes in the riparian vegetation along the creek from paperbarks (*Melaleuca* spp.) in the early 1900s to the appearance of mangroves in the 1950s (Figs 2A, B, 3). Between the 1950s and the 1970s, a mangrove community up to 80 m wide and comprising *Avicennia marina* trees to 5 m in height was restricted to the northern Creek bank near the creek mouth (Consultancy Study Group 1974; Hollingsworth 1975) (Fig. 3). Aerial photographs taken prior to 1970 also show the mouth of Currumbin Creek was unstable, migrating northwards during the extended periods of low freshwater runoff when sand, deposited by the longshore transportation and littoral drift, progressively sealed off the creek from the sea (Fig. 3). During floods, the creek cut a new entrance to the sea along the southern creek bank.

DISCUSSION

The discovery of an extensive *Zostera capricorni* community in Currumbin Creek was unexpected as previous surveys of the estuary had not reported seagrasses (Cambridge *et al.* 1974; Hyland *et al.* 1989; WBM Oceanics 2000), even though seagrasses grow in Tallebudgera Creek (Lewis & Ellway 1971; Shine *et al.* 1973; Hyland *et al.* 1989) and the Tweed River (Ellway & Hegerl 1972), estuaries within 10 km to the north and south of Currumbin Creek respectively. The dense subtidal seagrass community in Currumbin Creek contrasts markedly with the seagrass community in nearby Tallebudgera Creek, where *Zostera capricorni* occurs in small isolated patches in both the intertidal (Lewis & Ellway 1971; Shine *et al.* 1973; Hyland *et al.* 1989) and subtidal zones (Lewis & Ellway 1971). *Halophila ovalis* has not previously been recorded from Currumbin Creek and the species is not known to occur in Tallebudgera Creek.

Leaves of *Zostera capricorni* from Currumbin Creek are considerably longer than the 7–50 cm length range (den Hartog 1970; Poiner 1984) previously reported for the species. The larger leaf size in *Zostera capricorni* is attributed to the lack of emersion during low tides (Young & Kirkman 1975; Poiner 1984) and is known to occur in other creeks, lakes and rivers in south east Queensland where it is referred to as 'river' *Zostera*, in recognition of the larger growth form (C. Conacher, FRC Environmental, pers. comm., J. Phillips, pers. observ.).

Subtidal seagrasses growing along creek banks would be difficult to detect from aerial photographs, particularly from images taken during high tide or during periods of reduced water clarity which would occur on windy days or during turbid periods. Cambridge *et al.* (1974) and WBM Oceanics (2000) used aerial photographs apparently without ground truthing which may explain their failure to observe

FIG. 3. In 1952, extensive sand banks impeded marine flushing of lower Currumbin Creek. A small mangrove community grew on the northern bank of the creek (white arrow). A narrow stream meandered through the sandbanks to the sea (black arrows).

the Currumbin Creek seagrasses. However, Hyland *et al.* (1989) undertook spot dives in Gold Coast estuaries in 1987 and stated that 'seagrass was absent from Currumbin Creek'.

It is unlikely that seagrasses were growing in lower Currumbin Creek when Hyland *et al.* (1989) surveyed the locality in 1987, as between 1974 and 1992 sand dredging was generally removing between 40 000 to 300 000 m^{-3} of sand annually from the internal delta of Currumbin Creek upstream to the Gold Coast Highway bridge (Smith & Jackson 1993; D'Agata & McGrath 2002). Dredging physically destroyed the seagrass habitat and the associated sand destabilisation (Consultancy Study Group 1974; Hollingsworth 1975) would indirectly affect seagrass survival elsewhere in the creek by increasing water column turbidity and/or by burying plants, similar to that reported for other seagrass communities (Larkum & West 1983; Shepherd *et al.* 1989; Morton 1993) for distances up to 1.2 km from the dredge site (Ellway & Hegerl 1972; Onuf 1994).

Cessation of the sand dredging program probably contributed to the recovery of the Currumbin Creek seagrass community. Different seagrass species vary in the time required to recover from major disturbances which destroy the community (Meehan & West 2000). Recolonisation of *Zostera capricorni* in Botany Bay ravaged by storms which scoured and removed plants took 8 years (Larkum & West 1990), a time period consistent with the development of the large Currumbin *Zostera capricorni* community, assuming seagrass recovery commenced post 1992.

The areal extent of the Currumbin seagrass community in 2003 is far greater than in 1974 when seagrasses were restricted to inside the creek mouth (Consultancy Study Group 1974). Factors responsible for this expansion are not known but changes in salinity, turbidity, degree of light penetration and human-mediated disturbances affect estuarine seagrass communities. Although *Zostera capricorni* is a euryhaline species and is recorded from habitats experiencing salinities of 3–37 ppt (den Hartog 1970, Harris *et al*. 1980), the species can only tolerate salinities of 2 ppt or less for short periods of time (Kirkman 1975). Prior to 1974, Currumbin Creek was largely a freshwater stream (Consultancy Study Group 1974) and the estuarine section appeared to be confined to near the creek mouth, consistent with the restricted ecological distribution of seagrasses and mangroves to inside the creek mouth.

Changes to the environment and biota of Currumbin Creek over the last 4 decades have not been documented, a similar situation to other Australian east coast estuaries for which historical evidence documenting anthropogenically mediated changes has to be inferred from a variety of sources most notably early maps, air and ground photographs and descriptions (Bird 1974; Recher *et al*. 1993; McLoughlin 2000). Before 1974, Currumbin Creek was predominantly a freshwater stream, with the creek mouth blocked by sand deposition from the longshore transportation and littoral drift until washed away by major rain events (e.g. cyclones) once every 4–5 years (Delft Hydraulics Laboratory 1970, D'Agata & McGrath 2002). This is supported by riparian vegetation in the early 1900s of *Melaleuca* species (paperbarks) typical of brackish/freshwater coastal lagoons in southern Queensland (Dowling & Stephens 2001). After 1974, coastal engineering modifications has kept Currumbin Creek permanently opened to the sea, the marine flushing reducing water turbidity and increasing salinity much further upstream, promoting the observed spread of mangroves and seagrasses to approximately 5 and 2 km upstream respectively. Similar changes to vegetation with increases in salinity have been reported for other east Australian coastal river systems. Bird (1974) reported the loss of *Melaleuca ericifolia*, the invasion of freshwater swamps by saltmarsh vegetation and fluctuations between estuarine *Zostera* and freshwater *Vallisneria* populations were consistent with an increase in salinity in the once freshwater Gippsland Lakes, following the replacement of an intermittent natural opening to the sea with an artificial permanent opening. He also noted that the prolonged build-up of freshwater that preceded the reopening of the natural entrance by flooding is now short lived. The spread of mangroves further upstream in the Brisbane River has also been attributed to the greater penetration of the salt intrusion following dredging of the river mouth (Davie 1990).

Changes in sediment type is also indicative of the shift from freshwater/brackish to a marine conditions in lower Currumbin Creek. Muddy sediments on the northern bank near the creek mouth (Consultancy Study Group 1974; Hollingsworth 1975) are characteristic of sheltered environments which accumulate organic material and silt. Increased water movement from oceanic flushing reworks the sediments and removes organic material and silt and consequently the lower estuary bed is now composed of sand.

This study highlights the urgent need to document the estuarine biota at the species level. These surveys should be undertaken by biologists which the appropriate taxonomic and ecological expertise. Estuaries are dynamic systems, inhabited by species which are spatially and temporally variable in response to fluctuations in environmental parameters. Estuaries are also the sites of intensive human habitation and as such are often impacted by human mediated disturbances. Monitoring for several years is required to collect sufficient data on species composition and abundance in order to distinguish between natural variability and anthropogenically induced impacts on estuaries. Effective environmental management and biodiversity conservation must be based on science and monitoring of species is essential for evaluating whether management strategies are successful in protecting and conserving species. The extensive seagrass community in Currumbin Creek increases habitat heterogeneity for epiphytic algae, juvenile fish and invertebrates, substantially increasing aquatic species richness and as such is a valuable resource that should be not only mapped to adequately document the spatial extent of the community but also monitored and protected.

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LITERATURE CITED

Bird, E.F.C. 1974. Assessing man's impact on coastal environments in Australia. Pp. 66–75. *In*, *Australian UNESCO Committee for Man and the Biosphere. Report of the Symposium on the Impact of Human Activities on the Coastal Zone.* (Australian Government Publishing Service: Canberra).

Cambridge, M.L., Scott, J.J., Van Kempen, T.H. & Waterman, P. 1974. *Aquatic, wetland and terrestrial vegetation. Coastal Management Investigation. Internal Report.* (Co-Ordinator-General's Department, Queensland Government: Brisbane, Australia).

Clarke, S. & Kirkman, H. 1989. Seagrass dynamics. Pp. 304–345. *In*, Larkum, A.W.D., McComb, A.J. & Shepherd, S.A. (Eds), *Biology of Seagrasses.* (Elsevier: Amsterdam).

Coaldrake, J.E. 1961. An ecosystem of the coastal lowlands ("Wallum") of southern Queensland. *CSIRO Bulletin* **283.** (CSIRO: Canberra).

Co-Ordinator-General's Department, Queensland 1975. *Coastal Management. Queensland-New South Wales Border to Northern Boundary of Noosa Shire. Volume 2. Wetland and Aquatic Investigation.* (Queensland Government: Brisbane, Australia).

Consultancy Study Group 1974. *Environmental Investigation, Currumbin Creek, Gold Coast, Australia. Report of Stage 1.* (Land Administration Commission: Brisbane, Australia).

D'Agata, M. & McGrath, J. 2002. The use of Currumbin Creek as a sand reserve: Towards better dredging management. Pp. 495–501. *In*, Veloso, G. (Ed.), *Littoral 2002. The Changing Coast. Proceedings of the Sixth International Symposium, A Multi-disciplinary Symposium on Coastal Zone Research, Management and Planning.* (EUROCOAST Association - Portugal: Oporto, Portugal).

Davie, P. 1990. Invertebrate and intertidal communities of the estuary. Pp. 131–151. *In*, Davie, P., Stock, E. & Choy, D.L. (Eds), *The Brisbane River. A Source-book for the Future.* (Australian Littoral Society: Brisbane, Australia).

Delft Hydraulics Laboratory 1970. *Gold Coast, Queensland, Australia. Coastal Erosion and Related Problems.* Vols 1 and 2. (Delft: The Netherlands).

Den Hartog, C. 1970. *Seagrasses of the World.* (North Holland Publ.: Amsterdam).

Dowling, R.M. & Stephens, K. 2001. *Coastal wetlands of Coastal Queensland.* Vol. 1. *Mapping and survey.* (Environment Protection Agency, Queensland Government: Brisbane, Australia).

Ellway, C.P. & Hegerl, E.J. 1972. Fishes of the Tweed River Estuary. *Operculum* **2**: 16–23.

Harris, M., King, R.J. & Ellis, J. 1980. The eelgrass *Zostera capricorni* in Illawarra Lake, New South Wales. *Proceedings of the Linnean Society of New South Wales* **104**: 23–33.

Hegerl, E. & Timmins, R.D. 1973. The Noosa River tidal swamps: a preliminary report on flora and fauna. *Operculum* **3**: 38–43.

Hollingsworth, P. 1975. *Environmental investigation report: Crown reserve – R 68 Currumbin Creek, City of the Gold Coast, Queensland.* (Land Administration Commission, Queensland Government: Brisbane, Australia).

Hyland, S.J. & Bulter, C.T. 1988. The distribution and modification of mangroves and saltmarsh-claypans in southern Queensland. *Queensland Government Department of Primary Industries, Information Series* Q189004. (Queensland Government: Brisbane, Australia).

Hyland, S.J., Courtney, A.J. & Bulter, C.T. 1989. Distribution of seagrasses in the Moreton Region from Coolangatta to Noosa. *Queensland Government Department of Primary Industries, Information Series* Q189010. (Queensland Government: Brisbane, Australia).

Kirkman, H. 1975. A description of the seagrass communities of Stradbroke Island. *Proceedings of the Royal Society Queensland* **86**: 129–131.

Larkum, A.W.D. & West, R.J. 1983. Stability, depletion and restoration of seagrass beds. *Proceedings of the Linnean Society of New South Wales* **106**: 201–212.

1990. Long term changes of seagrass meadows in Botany Bay, Australia. *Aquatic Botany* **37**: 55–70.

Lewis, A.D. & Ellway, C.P. 1971. Fishes of Tallebudgera Creek, South Queensland. *Operculum* **1**: 60–63.

McLoughlin, L.C. 2000. Estuarine wetlands distribution along the Parramatta River, Sydney, 1788–1940: Implications for planning and conservation. *Cunninghamia* **6**: 579–610.

Meehan, A.J. & West, R.J. 2000. Recovery times for a damaged *Posidonia australis* bed in south eastern Australia. *Aquatic Botany* **67**: 161–167.

Morton, R. 1993. Fluctuations in wetland extent in southern Moreton Bay. Pp. 145–147. *In*, Greenwood, J.G. & Hall, N. (Eds), *Future Marine Science in Moreton Bay.* (School of Marine Science, University of Queensland: Brisbane, Australia).

Onuf, C.P. 1994. Seagrasses, dredging and light in Laguna Madre, U.S.A. *Estuarine, Coastal and Shelf Science* **39**: 75–91.

Poiner, I. 1984. A re-examination of the seagrass communities of North Stradbroke Island with an evaluation of their longevity. Pp. 228–237. *In*, Coleman, R.J., Covacevitch, J. & Davie, P. (Eds), *Focus on Stradbroke*. (Boolarong Publications: Brisbane, Australia).

Phillips, J.A., Koskela, T.V., Koskela, R. & Collins, D. 2008. The seagrass *Halophila minor* newly recorded from Moreton Bay. *In*, Davie, P.J.F. & Phillips, J.A. (Eds), Proceedings of the Thirteenth International Marine Biological Workshop, The Marine Fauna and Flora of Moreton Bay, *Queensland. Memoirs of the Queensland Museum – Nature* 54(1): 455–460.

Recher, H.F., Hutchings, P.A. & Rosen, S. 1993. The biota of the Hawkesbury-Nepean Catchment: Reconstruction and restoration. *Australian Zoologist* **29**: 3–41.

Saenger, P. & McIvor, C.C. 1975. Water quality and fish populations in a mangrove estuary modified by residential canal development. Pp. 753–765. *In*, Walsh, G.E., Snedaker, S.C. & Tees, S.C. (Eds), *Proceedings of the International Symposium on the Biology and Management of Mangroves*. Vol. 2. (University of Florida: Gainesville).

Shepherd, S.A., McComb, A.J., Bulthuis, D.A., Neverauskas, V., Steffensen, D.A. & West, R. 1989. Decline of seagrasses. Pp. 346–393. *In*, Larkum, A.W.D., McComb, A.J. & Shepherd, S.A. (Eds), *Biology of Seagrasses*. (Elsevier: Amsterdam).

Shine, R., Ellway, C.P. & Hegerl, E.J. 1973. A biological survey of the Tallebudgera Creek estuary. *Operculum* **3**: 59–83.

Smith, A.W. & Jackson, L.A. 1993. A review of Gold Coast beach nourishment 1972–1992. *Gold Coast Beaches and Waterways Report* No. 181. (Gold Coast City Council: Australia).

Thompson, C.H. 1975. Coastal areas of southern Queensland. *Proceedings of the Royal Society of Queensland* **86**: 109–115.

WBM Oceanics 2000. *Gold Coast Catchment Management Strategy. Aquatic and Riparian Ecological Assessment Study. Volume 2. Currumbin Creek.* (WBM Oceanics: Brisbane, Australia).

Young, P.C. & Kirkman, H. 1975. The seagrass communities of Moreton Bay, Queensland. *Aquatic Botany* **1**: 191–202.